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A Simplified Operation Approach of Multiple-Chiller Systems of Institutional Building during Vaccation

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Abstract

The simplified operation approach composed of the following strategies that were applied during summer semester and summer vacation in accordance with changes in building use: changing building indoor conditions; scheduling chiller during day and night; operating chillers with reduced heat loss from chilled water piping and adjusting chilled water flow rate. Implementation of these proposed strategies on existed multiple-chillers system serving institutional building that works on hot climate improves the system performance. The results show total energy saving of about 263.2 MWh which represents about 44.7% of the HVAC consumption during summer months of June to August. The simplified operation approach is easy to practice and requires minimal additional cost.

Keywords: Chiller operation strategies; Chiller performance; Energy saving; Part and full load operation.

1. Introduction

Air conditioning systems consume about 70% of the national energy generated in hot climate countries [1]. Efficient design and operation of HVAC systems may result in substantial energy saving that is beneficial particularly when energy demands exceed supplies and energy shortage is encountered.

Institutional buildings such as universities, colleges and schools, like the building considered in this research, are in partial use during months of June, July and August because summer semester takes place in the first two months and summer vacation occurs in August. The internal building load is reduced because less number of people, classes and equipment are working during summer semester whereas the reduction in the building load during summer vacation is caused by switching off the building's lighting and equipment, omitting the people load, less infiltration, and ventilation. The reduction in the building load demand during summer semester and vacation results in an oversized existed chilled water plants that work inefficiently most of the time. Therefore, matching the actual building load for different seasons and conditions with oversized HVAC system makes it more difficult to work at maximum performance as most of the system operating hours are at partial load [2].

In 2002, the Energy Systems Laboratory examined system operations in a number of newly retrofitted buildings and found that optimizing the systems can double energy savings and improve building comfort [3]. In another study conducted on more than 130 large buildings, it was found that efficient operation has

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produced typical savings of 20%, with payback periods less than three years [4]. An annual energy saving of about 31,900 MWh due to energy audit for 16 faculties at University of Malaya has been reported [5]. Two other studies conducted on educational buildings working on a hot and humid climate suggested energy reduction of 35.3% [6] and 41.87% [7] without compromising occupancies thermal comfort.

However none of the above studies has dealt with institutional buildings during vacation. Therefore, the present work aimed at evaluating some operation strategies that proposed for existing chillers working in institutional buildings to achieve the most efficient operation under partial load conditions (during summer semesters or vacation).

2. Building and HVAC System

The building under consideration is the Mechanical Engineering Department, College of Technological Studies, Kuwait. The building is a two-story institutional facility with total floor area of 7020 m². The overall heat transfer coefficients of building wall and roof are 0.562 and 0.187 W/m²K, respectively.

The building heating, ventilating and air-conditioning (HVAC) system consists of four air-cooled reciprocating (semi-Hermetic) chillers; three are on duty and one is standby. The chillers are using environment friendly refrigerant R-407c, with power of 142.42 kW each. The integrated distribution system consists of fourteen air-handling units (AHUs) and thirty fan-coil-units that serve workshops.

The detailed building and HVAC characteristics are modeled using a building simulation program (EnergyPlus) that is used to assess the proposed strategies and determine their significance.

3. Results and Discussion

3.1 Energy consumption of HVAC system

The chillers energy consumption during their seven months of operation (April to October) is shown in Fig. 1. It is clear that the chiller consumption increases as the outdoor conditions getting worse. It reaches its maximum value in the month of July then decreases in the succeeding months until the air conditioning system is shut down by end of October. Fig. 1 shows that the peak chillers consumption occurs during the month of July. It is true that this month represents the most severe weather conditions. But, the building is at partial use during June, July and August because the first two months are in summer semester and August is in summer vacation. Therefore, the high energy consumption during these months gives indication of the potential energy saving that could be attained if efficient operation strategies are used.

3.2 Changing building indoor conditions

Investigating the unexpected high consumption during the months of June, July and August indicates that the HVAC system was almost in normal operation despite the partial building use. An actual consumption of these months was compared with the simulated consumption (Table 1). Agreement between both consumptions is found to be 0.64, 0.81 and 2.31% in June, July and August, respectively. Then, a basic saving measure was applied to the simulated building by setting the indoor air temperature to 24°C at occupancy presence and set-back to 28°C while no occupants in June and July (summer semester) and set to 28°C all day in August (summer vacation). This approach showed energy saving of 11.2, 10.3 and 39.6% of the consumption during the months of June to August, respectively, with total saving of 119.9 MWh which represent 20.4% of the consumption during the stated months (Table 1).

In July and August of 2012, the indoor air temperature, in the building, has been set to 24°C and set-back to 28°C. The indoor building temperature and relative humidity were recorded in addition to the HVAC energy consumption to ensure that the applied operation strategy has no adverse effects. Application of this strategy resulted in actual saving of 31.7 MWh compared to the consumption of the same months of summer 2011. This saving represents about 7.93% of the total energy consumed by the HVAC during the months of July and August as listed in Table 2.

3.3 Scheduling chillers loading during days and nights

Figure 2 shows the ratio of the HVAC consumption during night (7pm-7am) to that during the full day (24 hours). Clearly, the consumption during the night is almost half (about 45%) the energy used during the full day. This happened, despite the reduction in the external building load while the internal building load is not changed during the tested days in summer vacation. The reason behind that is the dramatic drop of the COP at night as the average COP of chillers dropped from about 2.18 during the day to 0.63 at night. Thus 3.5 times energy is needed during nights to cover the same load during days.

Therefore, a new operation schedule is proposed to allow fewer chillers to work at night. Thus, the chillers are running at large load ratio and have better performance. The proposed day and night operation strategy is fed to the simulation program in order to find HVAC consumption and the resulted savings (Table 1). Monthly percentage savings of chiller consumption between 19.9 and 25.0% are experienced. This suggested strategy of operation would save about 136.5 MWh which represent about 23.2% of the chiller consumption during the months June to August. However, it should be pointed that applying this strategy should be integrated with monitoring the interior conditions of the building to define its boundaries. This is not presented here due to space limitation.

3.4 Operating chillers with reduced heat loss from chilled water pipes

The heat losses from chilled water piping system varies from chiller to another because the chilled water piping arrangement has different lengths from each chiller to the chilled water common point before distributed to the AHUs. The chilled water piping length of chillers 1, 2 and 3 are about 11, 25 and 95m, respectively. Thus, the chilled water out of chiller 3 may gain more heat from surroundings than the chilled water out of chiller 1 or 2.

In such hot environment with overall temperature difference, between ambient and chilled water, that may reach 30°C the heat loss is considerable. Heat loss per unit length for 6 inch pipes, during the stated 3 months, is 19.76 kWh. Energy saving of 1.52 MWh may be attained if chiller 3 is excluded from operation (less than 2 chillers are needed) during the three months. Additional saving is attained due to pumping power saving by using the chillers with short piping arrangements.

3.5 Reducing chilled water flow rate

As discussed in the above sections, the multi-chillers system is working at partial load during summer semester and summer vacation where less than half of its capacity can satisfactorily accomplish the building load. Consequently, all the related distribution systems including the water distribution can be reduced without affecting the HVAC system performance [8]. On contrary, reducing the chilled water flow rate may help improve the chiller performance by allowing the outlet chilled water temperature to reach the design point (7.5 °C) in partial load operation. Therefore, the chilled water can be circulated using two pumps (instead of the available 4 pumps) during days and one pump at nights. The reduction of the number of running pumps would save about 5.3 MWh of the pump consumption which represents about 0.90% of the HVAC energy consumption during the three stated summer months.

Conclusion

The simplified operation approach during summer semester and summer vacation composed of some chillers operation strategies that proposed to decrease their energy consumption in accordance with changes in building use. Implementation of the proposed operation strategies requires minimum cost. However, energy saving of about 263.2 MWh, which represent about 44.7% of the HVAC consumption during June to August, is achieved by applying the simplified operation approach. Most of the savings are due to chillers scheduling for days and nights and changing building indoor conditions during summer semester and vacation.

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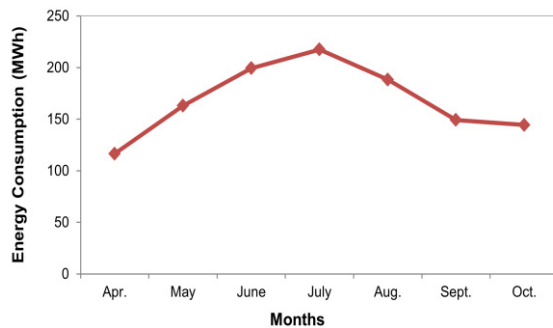


Figure 1: Energy consumption of the HVAC system during the operation months.

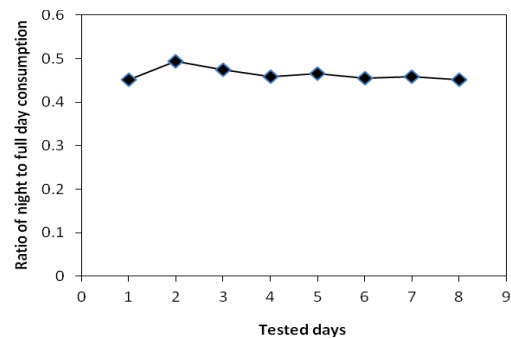


Figure 2: Ratio of chilled water plant consumption during night to that of the full day.

Table 1: Model verification and simulated energy saving. (Consumptions and savings are in MWh)

Months	HVAC consumption validation			Changing indoor conditions			Scheduling chiller loading		
	Actual	Simulated	% diff.	Consump.	Saving	%	Consump.	Saving	%
June	188.9	187.7	0.64	166.6	21.1	11.2	120.5	46.1	24.4
July	209.4	211.1	0.81	189.4	21.7	10.3	137.0	52.4	25.0
August	190.5	194.6	2.31	117.5	77.1	39.6	79.5	38.0	19.9
Total	588.8	593.4	0.78	473.5	119.9	20.4	337	136.5	23.2

Table 2: Measured energy saving due to changing indoor conditions.

Months	HVAC consumption (MWh)		Saving (MWh)	%
	2011	2012		
July	209.4	194.5	14.9	7.12
August	190.5	173.7	16.8	8.82
Total	399.9	368.2	31.7	7.93